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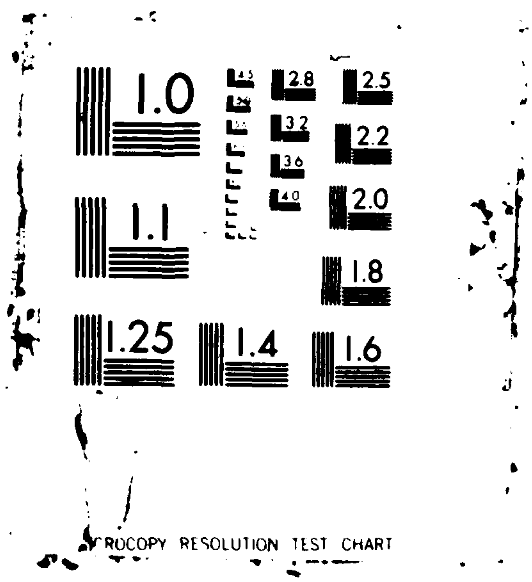
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Atmospheric Remote Sensing in Arctic Regions

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1. INTRODUCTION

The particular features which must be considered when sensing arctic regions from space platforms include a generally dry atmosphere, strong and rather persistent low-level temperature inversions, thin and low water content clouds which often cover large areas, a highly reflective snow or ice background in the visible spectrum, and weak thermal contrast between snow and cloud in the thermal infrared spectrum. These features provide some serious challenges to research and operational meteorologists who attempt to provide weather analyses and forecasts over vast regions which have a very low density of conventional-type observations. Polar-orbiting satellites provide an effective means for monitoring the arctic regions, and some results of cloud analyses in high latitudes are presented in this paper.

Models used in numerical weather prediction, general circulation studies, and climate studies require atmospheric temperature, water vapor, and wind information. Remote sensing of temperature and water vapor is generally weaker near the poles than it is at mid or low latitudes due to the same strong inversions and extreme backgrounds that plague the sensing of clouds. Remote sensing of winds needs improvements at all latitudes (Baker and Curran, 1985). Moreover, wind estimates by cloud tracking from geostationary satellites are not extended to polar latitudes due to the obliquity of the view and the problems in recognizing clouds above snow and ice backgrounds.

Microwave sensors will be playing an increasingly important role in monitoring arctic regions over the next decade. A microwave temperature sounder is currently a part of the Defense Meteorological Satellite Program (DMSP). The radiometer provides brightness temperatures at several frequencies in the oxygen absorption band between 50 and 60 GHz. A microwave system operating in the 183 GHz water absorption band is also being developed which will provide estimates of water vapor profiles; this system is planned for operation on a DMSP satellite in the early 1990s. A third system, the Special Sensor Microwave Imager (SSM/I) with a scheduled launch in mid 1987, is designed to provide estimates of several surface and atmospheric parameters including cloud amount over snow, cloud liquid water content, sea ice attributes and land surface temperature. Some aspects of these sensors for monitoring polar regions will be described.

2. CLOUD ANALYSIS IN THE ARCTIC FROM VISUAL/INFRARED SATELLITE SENSORS

The most critical component of atmospheric remote sensing in arctic regions is cloud analysis, not only due to the general importance of clouds to DoD airborne and spaceborne systems but also due to the poor sensing of clouds over polar regions by current weather satellites. The prime sensor of the DMSP is the Operational Linescan System (OLS), a cloud-detection imaging radiometer which senses thermal radiation at 10 to 13 μm and visible/near-infrared radiation at 0.5 to 1.0 μm. In both of these spectral regions, the contrast between clouds and snow cover or sea ice is generally poor so that image interpretation is more difficult in regions where snow or ice may be present.

The Air Force Global Weather Central (AFGWC) of the Air Weather Service has been operating an automated cloud analysis model since 1970. It was previously called 3DNEPH (Three-Dimensional Nephanalysis) and since 1983 has been called the RTNEPH (Real-Time Nephanalysis). Fye (1978) and Crum (this volume) describe the details of the 3DNEPH. It produces high resolution, three-dimensional analyses of clouds (cloud cover, altitude, and type) over the entire globe. The main source of data input is the infrared and visible digital imagery data from the DMSP OLS sensor. An alternate source is the Advanced High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting spacecraft. Conventional cloud surface observations, which are sparse in polar regions, are integrated with the satellite data. All sources of data are mapped into polar

stereographic projections of the Northern and Southern Hemispheres with a horizontal grid spacing of 25 nautical miles (eighth-mesh grid). The cloud analysis is updated every three hours at locations where new satellite or conventional data are available. The RTNEPH supports real-time cloud analyses and forecasts at the AFGWC. It is archived by USAFETAC as a world-wide record of cloudiness and is used extensively as a design climatology for new military systems.

The 3DNEPH/RTNEPH cloud maps are understandably questionable considering the limitations of currently available data. The RTNEPH satellite data processor consists of two parts - one for visible data and one for infrared data. In visible satellite imagery, clouds are considerably brighter than most background surfaces and thus can be discerned. On the other hand, cloud-free snow and ice covered areas have approximately the same brightness as clouds. Therefore, the visible data processor is not allowed to make a cloud amount calculation over grid points where snow or ice cover is believed to be present. The snow-cover data base (SNODEP) is of particular concern. It uses surface reports and climatology and may not represent the true snow cover condition over many gridpoints.

The infrared satellite data processor is thus the prime source of cloud analysis in the polar RTNEPH. Its ability to detect clouds depends on a comparison between a satellite-observed temperature and reference temperatures consisting of a surface background temperature and an atmospheric temperature-height profile. Some errors in the cloud analysis arise simply from poor estimates of reference temperatures. Other errors arise from the atmospheric temperature inversions common in polar regions. In general, clouds are colder than the background, and the colder they are the greater their height. Under-estimation or non-detection of cloud amount occurs when the cloud-top temperature is higher than the background temperature. This situation happens most frequently when low stratus clouds are present.

Hughes (1984) and Henderson-Sellers (1986) have evaluated available cloud climatologies and the 1979 3DNEPH archive. A comparison of some of the sources is given in Figure 1. They found considerable disagreement among the cloud climatologies at high latitudes; moreover, it was not possible to say which climatology was most accurate. In other words, not only is there uncertainty in the day-to-day remotely sensed cloud maps over polar regions, but there remains considerble uncertainty in the monthly average cloud cover over the entire polar regions.

Improved sensing of clouds over polar regions has been demonstrated and will be available in the future. The F-4 DMSP spacecraft tested a sensor providing images in the atmospheric window near 1.6 μm where

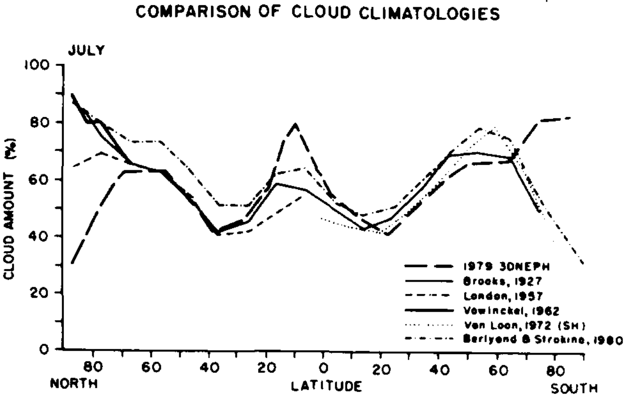

Figure 1. Comparison of Average Cloud Amount (% of total cloud cover from various sources for the month of July) with the July 1979 3DNEPH Archive. For this comparison, all data sources are averaged over latitudinal bands. Data were obtained from Hughes (1984) and Henderson-Sellers (1986).

the contrast between clouds and snow is very good. Figure 2 shows average spectra of liquid clouds (cumulus), ice clouds (cirrus) and snow cover measured from the AFGL KC-135 aircraft (Valovcin, 1978). The water droplets of liquid clouds reflect sunlight efficiently at 1.6 μm, much as they do at the shorter wavelengths which are generally used in imaging sensors. Ice particles absorb sunlight at 1.6 μm so that ice clouds or snow cover are much poorer reflectors at 1.6 μm than liquid clouds. However, an ice cloud reflects sunlight at 1.6 μm significantly better than snow cover because (1) the particles near the top of the cloud are orders of magnitude smaller than the snowflakes falling out the bottom and (2) the small ice particles near the cloud top scatter the 1.6 μm sunlight more efficiently than the much larger grains of a snow cover (Bunting and d'Entremont, 1982). Water clouds and snow cover exhibit similar properties in the

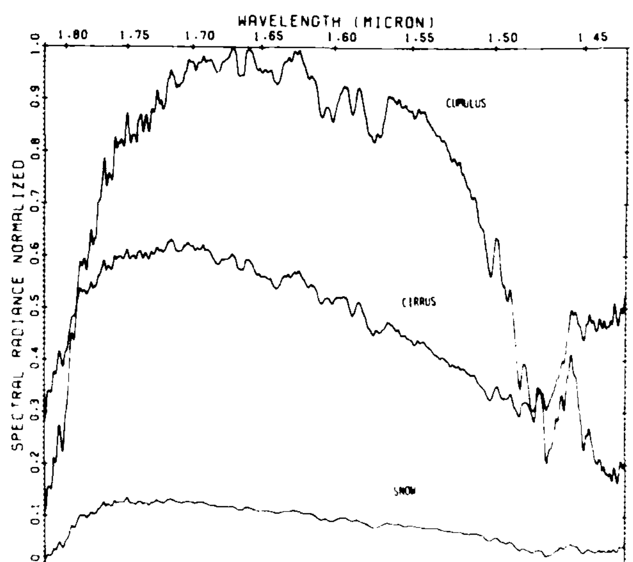

Figure 2. Average Spectral Radiance for 36 Cases of Cumulus, 32 Cases of Cirrus, and 56 Cases of Snow Obtained from Valovcin (1978). The plots are normalised such that the maximum radiance has a value of 1.0.

Figure 3. DMSP 1.6 μm Data (center strip) and Colocated Visible (left strip) and Thermal Infrared (right strip) for 17 Dec 1979. The upper left part of each image has clear skies and snow cover from Lake Ontario and the St. Lawrence Valley northward. Snow cover reflects poorly (looks dark) in the 1.6 μm data.

windows near 2.1 and 3.7 μm; however, the 1.6 μm window generally has the best cloud/snow contrasts. Figure 3 shows how snow cover or ice can be readily distinguished from clouds when an image taken at 1.6 μm is compared to a DMSP visual image.

Woronicz (1981) and Bunting and d'Entremont (1982) found simple and accurate algorithms to distinguish clouds and snow using both 1.6 μm and DMSP visual channels. Similar data with a much higher spatial resolution will be available in the future. The addition of a 1.6 μm channel and others to the current OLS was recently studied by DMSP. If modifications are approved, the data from these additional channels would be available to users in about 1995. On the NOAA polar-orbiting spacecraft planned for 1991 and beyond, the AVHRR will be modified to provide data at 1.6 μm during daytime (M. Matson, NOAA, personal communication). The current AVHRR provides 3.7 μm data day and night. Daytime imagery often shows distinct boundaries between liquid clouds and snow since sunlight from the more reflective clouds makes them appear significantly warmer than snow at 3.7 μm. However, this channel senses a mixture of thermal emission and reflected sunlight during daytime so that the 3.7 μm channel is more difficult to interpret than the 1.6 μm channel.

Arctic cloud analysis is particularly weak at night since the visual and near infrared channels generally require solar illumination of the scenes. There is one important exception. For a few days before and after full moon, there is sufficient lunar illumination for low-light-level sensing. Figure 4 is an example from DMSP two days after full moon. On the date of the picture there is no sunlight above 68 degrees North yet clouds are easily visible over the Norwegian Sea and the Barents Sea. Clouds can often be detected over land since they obscure landmarks such as forest boundaries, coastlines, frozen lakes or river valleys. Over snow cover, cloud shadows can be prominent. In the brighter phase of the moon, these pictures are useful for human interpretation of snow, ice and cloud boundaries. When there is less moonlight, they show the location of auroral activity.

3. THE SSM/I IN ARCTIC ENVIRONMENTS

3.1 The SSM/I

A new microwave satellite sensor shows promise of providing estimates of cloud amount over snow covered backgrounds. This information could be incorporated into the RTNEPH and help compensate for some of the cloud analysis deficiencies with visible and infrared satellite data over snow backgrounds. The sensor is called the Special Sensor Microwave/Imager (SSM/I). It will be flown on an operational polar-orbiting spacecraft of the DMSP which is scheduled to be launched in mid 1987. The SSM/I is intended as an all-weather meteorological and oceanographic sensor that was developed by the Hughes Aircraft Company with support by the Air Force and the Navy. The sensor is a passive, scanning radiometer which measures energy emitted from the earth/atmosphere system for 7 microwave channels over an earth swath that is 1394 km wide. The scan is conical and intersects the earth at a constant angle of 53.1 degrees. Each channel's frequency and polarization, scene station spacing, and effective field of view is listed in Table 1. There are four frequencies, 19, 22, 37, and 85 GHz, and two polarizations, vertical and horizontal, at each frequency except for the 22 GHz channel which only has vertical polarization. The SSM/I measures emitted energy at intervals of 25 km, except at 85 GHz where the intervals are 12.5 km. The effective field of

Figure 4. Low-light-level Imagery from the Photomultiplier Tube Sensor on DMSP F-7, 8 Jan 1985. The image shows reflected moonlight from clouds and snow cover, as well as lights of cities of Europe.

TABLE 1. SSM/I CHANNELS AND RESOLUTION

Frequency(GHz) & Polarization (V=vertical, H=horizontal)	Scene Station Spacing (km)	Effective FOV (km)
19.35 V	25	55.3
19.35 H	25	55.1
22.2 V	25	48.6
37 V	25	32.2
37 H	25	32.7
85.5 V	12.5	14.8
85.5 H	12.5	14.8

view decreases as the frequency increases and ranges from about 55 km at 19 GHz down to about 15 km at 85 GHz. Further details of the SSM/I are given by Hollinger and Lo (1983).

Relationships between the brightness temperature (the physical temperature a black body emitting the same intensity of radiation would have) observed from the various channels provide a means to determine several geophysical parameters. SSM/I software contains algorithms for estimating values for 11 different parameters which are listed in Table 2. The parameter extraction algorithms are discussed by the Hughes Aircraft Company (1986a). This reference also contains the actual computer code listings. All the algorithms for extracting environmental parameters, except for the ice parameters and the surface characteristic parameter use the brightness temperatures as independent variables in linear regression equations. The regression coefficients are determined using climatology, geophysical models, radiative transfer models, and an inversion algorithm. The ice algorithm is developed directly from physical relationships rather than regression. (See Lo, 1983 and Hughes Aircraft Company, 1985 for more details on the extraction of environmental parameters.)

The TYPE parameter (Item 11 in Table 2) algorithm uses the surface characteristic data base which is part of the SSM/I software package. It is a fixed data base, of approximately 10-km resolution, that distinguishes between ocean, land, coast, permanent oceanic ice and possible ice, the Antaractic ice cap, and possible heavy vegetation. Locations coded as possible ice are determined to be TYPE parameter ice or ocean from the ice concentration calculation portion of the ice algorithm. Locations tagged as ocean, coast, permanent oceanic ice, or Antarctica are accepted to be so, since such things presumably do not change. The TYPE parameter for locations coded as land or possible heavy vegetation are determined from a decision tree of brightness temperature discriminators. The descriminators are based on numerical models, published literature, and observations of SMMR (Scanning Multichannel Microwave Radiometer) data (Hughes Aircraft Company, 1985).

TABLE 2. GEOPHYSICAL PARAMETERS ESTIMATED FROM SSM/I DATA

(1) SW - Surface Wind Speed (Ocean)

(2) IC, IE, IA - Ice Concentration, Edge, Age (1st year or multiyear)

(3) RO, RL - Rain Rate (Ocean and Land)

(4) LWO, LWL - Liquid Water Content of Rain (Ocean and Land)

(5) CWO, CWL, CWI, CWS - Cloud Water Content (Ocean, Land, Ice, and Snow)

(6) WVO - Atmospheric Water Vapor Content (Ocean)

(7) SM - Soil Moisture (Land - Except Heavy Vegetation)

(8) SNW, SNE - Snow Water Content, Edge

(9) STL, STS - Surface Temperature (Land and Snow)

(10)CAL, CAS - Cloud Amount (Land and Snow)

(11)TYPE - Surface Characteristic (ocean, sea ice, coast, flooded land, vegetation, arable soil, desert, heavy rain, snow, frozen soil/wet snow (indistinguisable to SSM/I), and glacial)

3.2 The Cloud Amount Over Snow Algorithm

A discussion of why clouds over a snow covered background will be discernable with the SSM/I follows. Also, the algorithm for determining the percent cloud amount over snow surfaces is discussed.

Radiation measured by the SSM/I (in either of 2 orthogonal polarizations) comes from three sources - atmospheric emission, surface emission, and atmospheric emission reflected from the surface. Energy from the latter two sources is attenuated by some loss factor in passing through the atmosphere. For microwave radiation, the important atmospheric parameters that attenuate are water vapor, oxygen, and liquid water (both in the form of cloud water and rain).

At 85 GHz, dry snow has a low emissivity. This means that a snow surface will appear quite cold under a clear, cold atmosphere. Simulated 85 GHz brightness temperature values of less than 220 K and occasionally less than 200 K have been calculated for snow surfaces (Hughes Aircraft Company, 1985). The low emissivity of snow means that it is also a good reflector. Absorption and emission by cloud-sized droplets is also strong at 85 GHz. Thus, 85 GHz radiation from clouds above a snow covered surface will be strongly reflected upward, adding to emission reaching the sensor directly. Comparison of cloudy and non-cloudy areas over a snow background in a 85 GHz brightness temperature image will show relatively warm areas in the presence of clouds.

In the initial development of an algorithm for cloud amount over snow, it was apparent that the 85 GHz channels would provide much of the information. It was also desired to retrieve, if possible, information on the spatial variability of clouds within the resolution of the approximately 45 km area used by AFGWC in their RTNEPH. A single estimate of cloud amount is based on a 3x3 array of adjacent dual polarized 85 GHz samples with an all-frequency (7 channel) scene at its center. In formulating an algorithm, typical values of 85 GHz polarization (85 GHz vertical brightness temperature minus 85 GHz horizontal brightness temperature) for a variety of snow background conditions for clear and cloudy cases were calculated (Hughes Aircraft Company, 1985). They are listed in Table 3. By summing the polarization differences shown in Table 3, it is seen that a set of nine clear 85 GHz footprints should have a total polarization difference of 135 to 180 K. Likewise, a set of nine cloudy 85 GHz footprints should have a polarization difference total of 45 to 72 K which is much less than for the clear set. It is logical to expect that the percent cloud amount over a set of nine adjacent 85 GHz footprints is related to the total of polarization difference.

Further analysis indicated that there is a significant effect of clouds on 37 GHz brightness temperatures also. Simulated 37 GHz (vertical and horizontal polarizations) and 85 GHz (vertical and horizontal polarizations) brightness temperature values for clear and overcast conditions with several different surface temperatures and water contents of snow were calculated using the Air Force Geophysics Laboratory's RADTRAN model computer code (Falcone, et. al., 1979). The cloud characteristics for the overcast condition were fixed. The cloud was a layer of stratus/stratocumulus between .5 and 2 km altitude with a liquid water content of .15 g/m^3. Interpolated values of these brightness temperatures were combined, using a random number generator (uniform distribution) to create clear fields of view (all nine 85 GHz footprints clear), one 85 GHz footprint overcast (any one of the nine), two 85 GHz footprints overcast (any two of the nine), etc. through all nine 85 GHz footprints overcast. A four step regression produced a percent cloud amount over snow estimation equation that accounts for 95.9 % of the modelled variance. An error analysis of this estimation equation determined a rms error of the estimated percent cloud amount of 3.2 % (Savage, 1986).

Hughes Aircraft Company (1986a and b) has developed an operational version of the cloud amount over snow algorithm. It is:

$$CAS = C_0 + C_1 {}^*T(37V) + C_2 {}^*T(37H)$$

$$+ C_3 {}^*SUMT(85V) + C_4 {}^*SUMT(85H)$$

TABLE 3. DIFFERENCES BETWEEN THE 85 GHZ VERTICAL AND HORIZONTAL POLARIZATION VALUES OVER SNOW

Clear Atmosphere:

20 K - cold, shallow snow
15 K - cold, deep snow
20 K - warm, shallow snow
20 K - warm, deep snow

Cloudy Atmosphere:

5 K - cold, shallow snow
5 K - cold, deep snow
8 K - warm, shallow snow
7 K - warm, deep snow

CAS is the percent cloud amount over snow; T(37V) is the brightness temperature at 37 GHz - vertical polarization; T(37H) is the brightness temperature at 37 GHz - horizontal polarization; SUMT(85V) is the sum of the 85 GHz - vertical polarization brightness temperature at an all-frequency channel scene station and its 8 surrounding 85 GHz - vertical polarization brightness temperatures; SUMT(85H) is the sum of the 85 GHz - horizontal polarization brightness temperature at an all-frequency channel scene station and its 8 surrounding 85 GHz - horizontal polarization brightness temperatures. The values of the coefficients in the above equation are: C_0 = -189.5000; C_1 = -0.9710; C_2 = 0.7400; C_3 = -0.1987; C_4 = 0.3678. Hughes has also developed an operational cloud amount over land algorithm. It is similar to the algorithm for over snow, except that the 37 GHz - vertical polarization brightness temperature is not used, and of course the coefficients are different.

Although only algorithms for cloud amount over snow and over land have been derived, the SSM/I is also expected to provide a capability for estimating cloud amount over the oceans. However, visible and infrared data usually are better sources for cloud amount estimates over oceans, and consequently the initial emphasis of the SSM/I cloud amount investigation will be restricted to situations in which the surface is snow covered or is land.

4. SATELLITE MICROWAVE SOUNDERS IN THE ARCTIC

4.1 Temperature Soundings

Because of the detrimental effect of clouds on retrieving temperature and moisture profiles from infrared radiometers, the DoD has placed increasing emphasis on the use of microwave sensors from meteorological satellites. The Special Sensor Microwave Temperature Sounder (SSM/T) is a

radiometer that measures radiation in the 50-60 GHz oxygen absorption band and is currently a part of the DMSP sensor complement. The SSM/T is a 7-channel scanning system which is designed to provide atmospheric temperature estimates from the surface to mid-stratospheric levels. The weighting functions for the SSM/T channels are shown in Figure 5. These weighting functions for oxygen, which is a uniformily mixed gas within the regions of interest, are nearly independent of temperature. The highest weighting function peaks near 28 km and the channel farthest from the center of the absorption band peaks at the surface. A statistical technique, which relies on correlations between the observed radiances or brightness temperatures and the actual temperature profile, is used during the retrieval process. From these seven measurements, temperatures at the mandatory pressure heights plus the layer thicknesses are retrieved.

The SSM/T scans across track and has a field-of-view of 14.4° which gives a footprint on the surface of about 200 km. With this rather coarse resolution, the data are useful only at the synoptic scale. Simulations and recent evaluations of temperature errors from the SSM/T have shown that the sensor provides estimates of temperatures which have an rms error of about 2° K at heights from 3 to 30 km; the rms error near the surface is considerably larger and is about 6° K. The temperature errors from the SSM/T as a function of height are shown in Figure 6. The errors are based on simulations using a number of radiosondes for the mid-latitudes in spring. The standard deviation of the data set is also indicated in Figure 6. The retrieved temperature errors are one-half to one-third the errors of using climatology instead of the retrieval.

The retrieval errors shown in Figure 6 are for the mid-latitudes in spring. Since the strong surface inversion which persists in the Arctic during much of the year is not depicted accurately from temperature profiles retrieved from space sensors, the temperature errors may be larger for arctic regions. It is the occurrence of the generally large temperature gradients in the lower 2 km of the atmosphere that gives rise to the large temperature uncertainties near the surface illustrated in Figure 6.

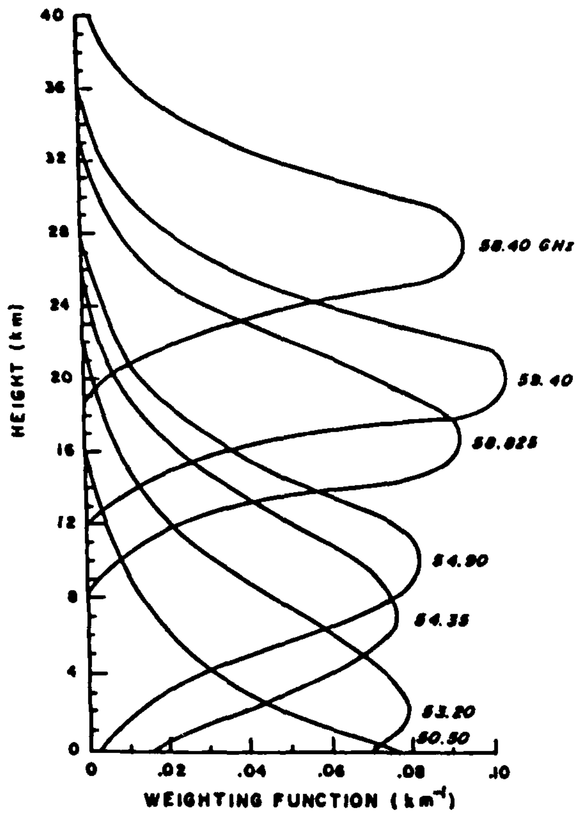

Figure 5. SSM/T Weighting Functions Used to Retrieve Temperature Profiles

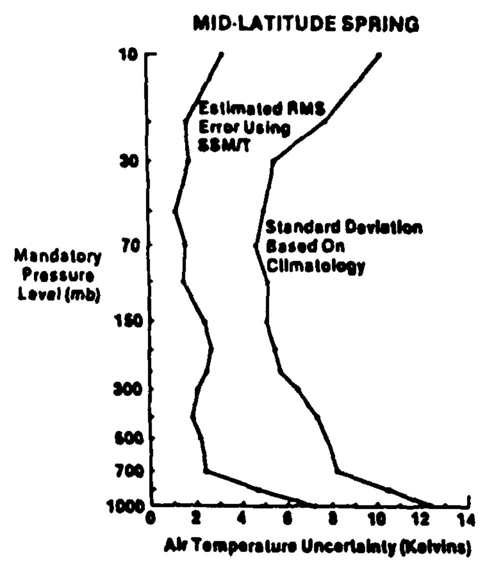

Figure 6. Estimated RMS Retrieval Error Using SSM/T Simulations Compared to Climatological Variability

Temperature profiles are used as a key input to numerical models. In the case of space-based estimates of atmospheric temperatures, a method has to be devised to determine the representativeness of the observations before they can be incorporated into the models. The coefficients which are used in the linear equations to determine the temperature and thickness values from satellite measurements are updated using comparisons between radiosonde temperatures and the retrieved temperatures. This technique works well in mid-latitudes where the density of radiosondes is adequate (Chisholm, this Volume), but it has serious shortcomings in regions such as the Arctic where the number of radisonde stations available for the comparisons is very small. Since the number of radiosonde stations in the Arctic is unlikely to change siqnificantly, it is necessary to change the update procedure used to derive the coefficients in the retrieval process or to develop improved retrieval techniques. The Air Weather Service is currently conducting an evaluation of the SSM/T temperature and thickness estimates. Part of this evaluation includes the

development of techniques to use the data more effectively in their numerical models for all parts of the globe.

4.2 Water Vapor Soundings

In contrast to oxygen or carbon dioxide which are well mixed gases in the atmosphere, water vapor is highly variable. This variability leads to added complications in the retrieval of water vapor from satellites. The best microwave region for the estimation of water vapor is near the strong water vapor absorption band at 183 GHz. An example of the weighting functions of several frequencies within this band is shown in Figure 7. The weighting functions are for a mid-latitude summer atmosphere in which the relative humidity is at a constant 10% from the surface to 20 km. The low relative humidity used in this simulation provides weighting functions which may also apply to regions of the Arctic. A serious difficulty, however, is that the weighting functions depend on the vertical distribution of water vapor. It is also noted in Figure 7 that the weighting functions are different over land than they are over the oceans. At present, there is a need to determine the weighting functions that will be applicable for regions which are snow or ice covered. Figure 7 shows that the functions may be either positive or negative. This is to be compared with Figure 5 in which the weighting functions for temperature are always positive.

Although the microwave region is perferred for atmospheric soundings because of its relative insensitity to cloud, 183 GHz is a sufficiently high frequency that clouds do play a role in the 183 GHz brightness temperature observed from space. This is illustrated in Figure 8 which is the result of a water vapor retrieval in the presence of a cloud (Wilheit, private communication). The cloud is 1 km thick and its base is at 4 km. The water vapor profile used in this simulation is indicated by the solid line; it shows a region of 100% relative humidity throughout the depth of the cloud. The dashed curves are the retrieved water vapor profiles using a three-channel radiometer in the 183 GHz region plus window channels at lower frequencies. Each dashed curve is for a different cloud water content within the 1-km thick cloud and varies from zero to 20 mg/cm^2. It is seen that large gradients in water vapor are not resolved and that clouds have a detrimental effect on the retrieved values.

Despite the limitations of a space-based microwave radiometer for water vapor estimates, it is still considered to be the best near-term solution for obtaining the required information on the global distribution of water vapor. Thus, the DMSP is proceeding on the development of a satellite-borne water vapor sounder which is designated as the SSM/T-2. It is planned for launch in the early 1990s. Further simulations to improve the retrieval algorithms are being conducted, and an important experimental program using a 183 GHz radiometer is being carried out by NASA. Such a sensor may

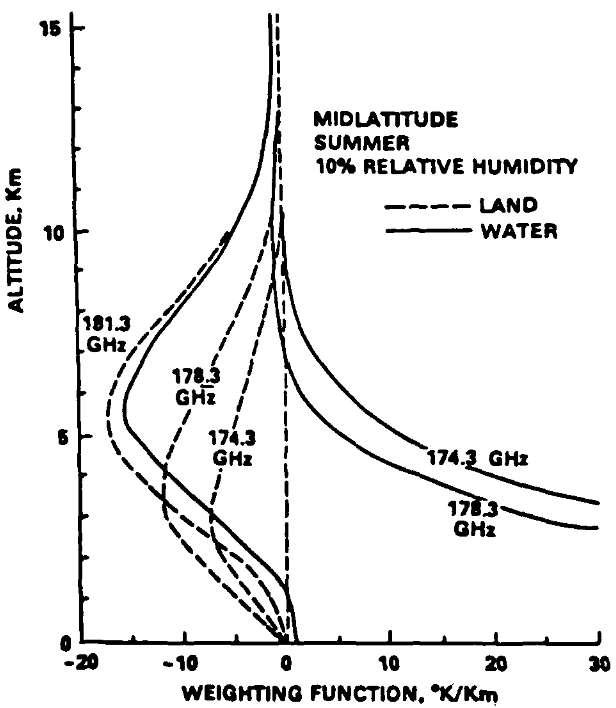

Figure 7. Weighting Functions for Frequencies Near 183 GHz through an Atmosphere with 10% Relative Humidity for the Mid-latitudes Over Land and Ocean

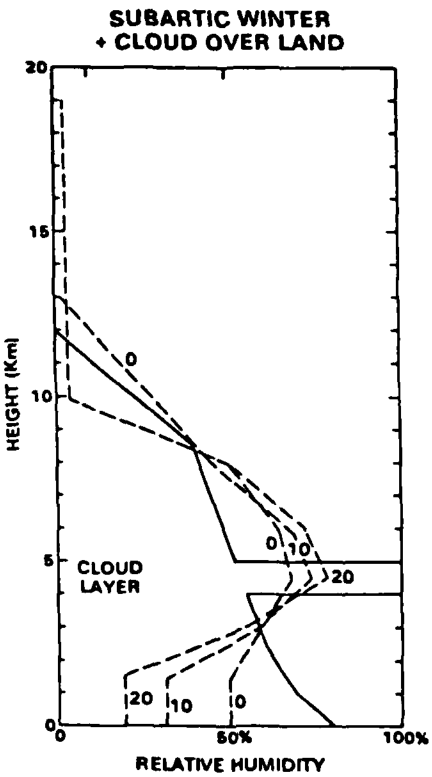

Figure 8. Simulated Retrieval of Relative Humidity in the Presence of a Cloud. The solid curve is the actual relative humidity profile and the dashed curves are the retrieved profiles for cloud water contents of 0, 10, and 20 mg/cm^2 throughout the 1-km depth of the cloud.

provide some much-needed information on the presence of the thin clouds which often occur near the top of the low-level inversion prevalent in arctic regions.

4.3 Active Sensors

With the inherent difficulties of passive systems for remote temperature and moisture soundings, considerable effort is being placed on the development of active systems for obtaining improved sensing of the atmosphere. Much of this development within the Air Force is focused on a lidar system for the remote detection of wind on a global scale. NASA also has several programs which could lead to lidar measurements of temperature and moisture profiles from space. Since all the current sensors have deficiencies for probing arctic regions, the availability of these new active sensors should provide a greatly improved capability for monitoring the higher latitudes where more conventional measurements remain sparse. Moreover, the temporal and spatial sampling of polar regions by active sensors should be relatively good, since the polar-orbiting platforms, which are best for active systems, view the polar regions much more frequently than the lower latitude regions.

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The particular features which must be considered when sensing arctic regions from space platforms include a generally dry atmosphere, thin and low water content clouds which often cover large areas, a highly reflective snow or ice background in the visible spectrum, and weak thermal contrast between snow and cloud in the thermal infrared spectrum. In recent years, more attention has been given to the problem of identifying clouds in arctic regions. An investigation of operational cloud analysis programs for arctic regions has been initiated; results from this study have shown that clouds are often specified in regions which turn out to be generally cloud-free and vice versa. Some possible reasons for this error will be presented. Results of discriminating clouds from a snow background using multi-spectral visible and near IR sensors will also be given. → next page

Infrared

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A new Special Sensor Microwave/Imager (SSM/I) operating at four frequencies from 19 to 85 GHz is designed to provide estimates of several surface and atmospheric characteristics. The SSM/I is scheduled for launch in 1987. Several parameters which will be estimated from SSM/I data are of particular interest to arctic regions. These include snow parameters, sea ice attributes, cloud amount over snow, cloud liquid water content, soil moisture, and land surface temperature. As an example of parameter retrieval from SSM/I data, the basis for estimating cloud amount over a snow surface will be discussed. A microwave radiometer for temperature soundings is currently a part of the Defense Meteorological Satellite Program (DMSP). The radiometer provides brightness temperatures at several frequencies in the oxygen absorption band between 50 and 60 GHz. Retrieval algorithms have been developed which lead to temperature profiles on a global scale. In addition, a microwave system operating in the 183 GHz water absorption band is being developed which will provide estimates of water vapor profiles; this system is planned for operation on a DMSP satellite in the early 1990s. Some attributes of these systems as they relate to arctic conditions will be presented.

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